Federal Technology Alert

A publication series designed to speed the adoption of energy-efficient and renewable technologies in the Federal sector

Prepared by the New Technology Demonstration Program

SERDP
Strategic Environmental Research and Development Program
Improving Mission Readiness through Environmental Research

Refrigerant Subcooling

Technology for improving cooling system performance

Refrigerant subcooling is proving to be a reliable energy-saving alternative to increasing the cooling capacity of air-conditioning systems in many facilities. As shown below, the technology modifies a standard direct-expansion, vapor-compression refrigerant system with the addition of a heat exchanger in the liquid line of the system.

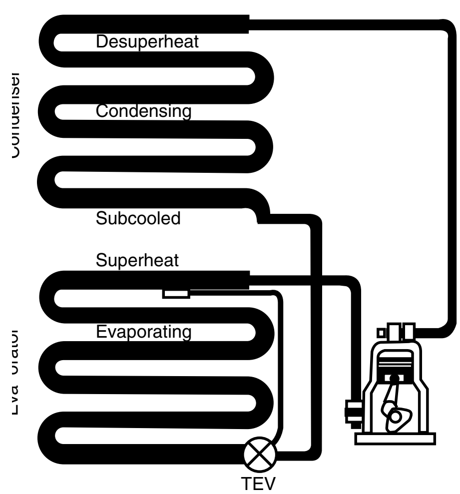
This *Federal Technology Alert* (FTA), one of a series on new technologies, describes the theory of operation, energy-saving mechanisms, range of applications, and field experience for the refrigerant subcooling technology. Featured is a subcooling device with an external heat sink. One such subcooling device, called the Fisher Tri-Temp System (FTTS), is patented by Ralph H. Fisher.

Energy-Saving Mechanism

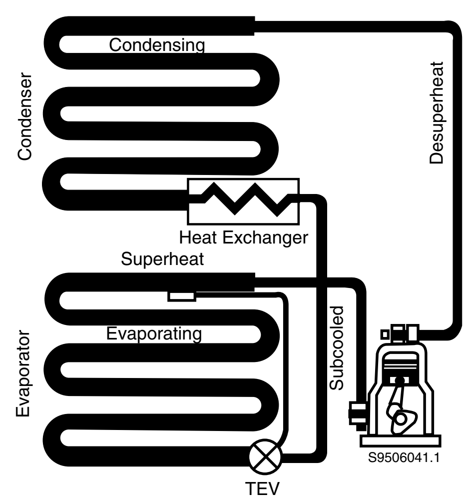
A refrigerant subcooling unit provides additional cooling capacity and can also reduce energy consumption for increased overall system efficiency. It works best where year-round outdoor temperatures are high and constant. Effectiveness of the technology is based on the properties of refrigerants, which absorb latent heat until they vaporize. The subcooling increases refrigerant cooling capacity, and use of an external heat sink (either mini-cooling tower or ground-source water) reduces compressor power. Although detailed operation and maintenance data are generally lacking, the technology is proving particularly applicable in direct-expansion vapor-compression air-conditioning equipment, especially where old units are being replaced or where new construction/expansion or new installation is planned.

Technology Selection

Refrigerant subcooling is one of many energy-saving technologies to emerge in the last 20 years. The FTA series targets technologies that appear to have significant untapped Federal-sector potential and for which some Federal installation experience exists. New technologies were identified through advertisements for technology suggestions in the Commerce Business Daily and trade journals, and through direct correspondence. Numerous



Normal System



System with Subcooler

responses were obtained from manufacturers, utilities, trade associations, research institutions, Federal sites, and other interested parties.

Technologies suggested were evaluated in terms of potential energy, cost, and environmental benefits to the federal sector. They were also categorized as those that are just coming to market and those for which field data already exist. Technologies classified as just coming to market are considered for field demonstration through the U.S. Department of Energy s Federal Energy Management Program (FEMP) and industry partnerships. Technologies for which some field data already exist are considered as topics for FTAs. The refrigerant subcooling technology was found to have significant potential for federal-sector savings.

Potential

Analysis of a large sample (nearly 25% by floor area) of Federal facilities indicates a major, untapped energy conservation potential in the Federal sector. The subcooling technology not only provides for additional cooling capacity but can also reduce compressor power, leading to higher overall system efficiency. Besides saving energy, subcooling benefits the environment through reduced emissions of sulfur and nitrogen oxides and carbon dioxide associated with power generation.

Application

Qualitative field testing and theoretical analyses have shown the subcooling technology to be technically valid and economically attractive. The technology is generally applicable to direct-expansion vapor-compression equipment with or without head pressure control. Potential Federal-sector applications for refrigerant subcooling include direct-expansion vapor-compression air-conditioning equipment. The subcooling technology with external heat sink is especially useful under the following conditions:

- for high-temperature[a] applications, generally in conjunction with air-conditioning and heat pump systems (split or packaged systems) or reciprocating, screw or scroll chillers
- where chillers, split systems or packaged systems are to be replaced (equipment that is 15 years or older or where new construction/expansion or new installation is planned).

External heat sink subcooling devices (such as FTTS) are not recommended for the following applications:

- as add-on devices
- large centrifugal chillers
- off-peak cold storage
- low-temperature applications
- insufficient space for a mini-cooling tower
- in some cases a system with a water-cooled or evaporatively cooled condensers may be as effective as external heat sink subcooling devices.

Field Experience

More than 12 systems have been fitted with external heat sink subcooling devices, seven of these in the Federal sector (IRS headquarters in Washington, D.C.). Detailed performance of the technology has not been monitored at any of the sites. Building owners/operators have noticed reduced electric consumption after the retrofit. The operator at the IRS site is satisfied with the performance of the retrofits and is considering installing another one at that site.

Typical installation cost is $700/ton (approximately $200/kW) of cooling capacity. A typical yearly maintenance cost for the air-conditioning system is about $25/ton to $35/ton, and for the mini-cooling tower (external heat sink) it is about 2% of the cost of the cooling tower. When an external heat sink subcooling device, such as an FTTS, is installed with the air-conditioning system the outdoor unit is downsized; therefore, the general maintenance of the air-conditioning system decreases and there is an additional maintenance associated with the external heat sink (mini-cooling tower). In general, reduction in cost of maintaining the air-conditioning system is offset by the additional cost for maintaining the mini-cooling tower. The general maintenance of the air-conditioning system with an external heat sink subcooling device is similar to a conventional system. The mini-cooling towers will need periodic maintenance, such as checking the pre-filter on the makeup water and cleaning the sump.

Case Study

A qualitative analysis was performed on the basis of whole-building utility billing information from one private-sector site. Southeastern University (SU), in Washington, D.C., has a 22-year-old, 100-ton (352-kW) chiller system with a cooling tower. This system was replaced with two 20-ton (70-kW) remote condensing units, each fitted with an external heat sink subcooling device, including two mini-cooling towers. Comparison of utility bills from pre- and post-replacement periods indicated savings in demand charges and energy charges of $5,819/year. On the basis of whole-building utility billing data alone, it is difficult to quantify the actual savings. Because there was no other change to the building during the one-year period (peak demand and energy consumption remained unchanged during winter months), significant portion of the energy and demand reduction can be attributed to the replacement system with an external heat sink subcooling device.

Implementation Barriers

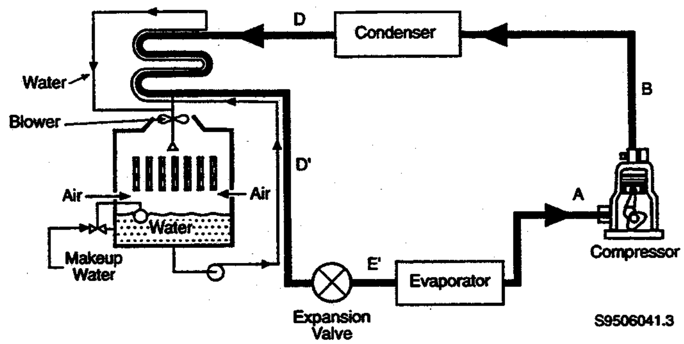
There are no known barriers for implementing the subcooling technology. Federal energy managers who are familiar with refrigerant subcooling systems are listed in this FTA. The reader is invited to ask questions and learn more about the technology.

(a) Low-temperature application refers to applications with evaporator temperatures less than -10¡F, medium-temperature refers to -10¡F to 30¡F evaporator temperatures, and high-temperature refers to evaporator tempertures greater than 30¡F.

Federal Technology Alert

Refrigerant Subcooling

Technology for Improving Cooling System Performance



Abstract

Refrigerant subcooling is a demonstrated and reliable way of increasing cooling capacity, and is proving to have energy-saving potential to conventional air-conditioning systems for Federal facilities. Effectiveness of the technology is based on the properties of refrigerants, which absorb latent heat until they vaporize. In this new implementation (shown above) smaller sizes of compressor, condenser, and thermostatic expansion valves are incorporated, as is a mini-cooling tower. This Federal Technology Alert (FTA) focuses on a relatively new variation on subcooling technology, which utilizes an external heat sink (mini-cooling tower or ground-source water). In general, the benefits of subcooling are higher in regions with constantly high year-round temperatures (1200 or more cooling degree-days to base 65°F). Several of these new subcooling devices have been installed in the Washington, D.C., area, seven of them in Federal facilities. Most installations are custom-designed to obtain optimum system performance, and data related to operation and maintenance are somewhat sparse. However, the technology is proving particularly applicable in direct-expansion vapor-compression air-conditioning equipment, especially where old units are being replaced or where new construction/expansion or new installation is planned. It is not recommended as an add-on device.

This FTA provides information and procedures that a Federal energy manager needs to evaluate subcooling with external heat sink. The New Technology Demonstration Program (NTDP) technology selection process and the general benefits to the Federal sector are outlined. The process of refrigerant subcooling and its energy-saving and other benefits are explained. Guidelines are provided for appropriate application and installation. In addition to a methodology on how to estimate energy savings potential from subcooling installation, a case study is presented to give the reader a sense of the actual costs and energy savings. Current manufacturers, technology users, and references for further reading are included for prospective users who have specific or highly technical questions not fully addressed in this Technology Alert.

Contents

About the Technology

Refrigerant subcooling has long been used in low- and medium-temperature[a] refrigeration systems (Couvillion et al. 1988; Miller 1981). The modified refrigeration cycle is based on the properties of refrigerants, which absorb latent heat (instead of rejecting it) until they vaporize. The properties of refrigerants make it impossible for the condensation process to reject the latent heat completely.

The refrigerant subcooling technology modifies a standard direct-expansion, vapor-compression refrigerant system through the addition of a liquid line heat exchanger downstream of the condenser. In a standard vapor-compression process, a 10°F to 15°F (5.6°C to 8.3°C) refrigerant subcooling range is normally achieved through ambient cooling in the condenser. The amount of subcooling can be increased by using an external heat sink. Subcooling the refrigerant increases the cooling capacity and may decrease the compressor power (depending on the subcooling technology), thereby increasing the overall efficiency of the system.

Three types of subcoolers are currently being manufactured: 1) systems in which suction-line heat of the vapor-compression system acts as a heat sink, 2) systems incorporating a small (but more efficient) secondary vapor compression system for subcooling (this type is generally referred to as "mechanical subcooling"), and 3) systems with an external heat sink. They are described later in this report. This FTA focuses on an external heat sink subcooling device (Figure 1). One such subcooling device called the Fisher Tri-Temp System (FTTS), patented by Ralph H. Fisher, is manufactured by Automatic Controls Inc., Ellicott City, Maryland. The FTTS technology, which holds promise for the Federal sector, uses a heat exchanger and a mini-cooling tower (or ground source) as a heat sink (U.S. Patent 4,553,401, November 19, 1985).

Field and laboratory tests indicate that for every additional 2°F (1°C) subcooling, there is an increase of 1% in refrigerant cooling capacity (Miller 1981; Linton et al. 1992). Miller (1981) also reported 20% to 30% reduction in compressor power with mechanical subcooling. The subcooling technologies, which use external heat sinks (such as FTTS) to reject heat from refrigerant, can also downsize the compressor and the condenser. Therefore, these devices increase the cooling capacity and reduce the compressor power consumption, which leads to an overall increase in the system efficiency and reduced demand. However, an understanding of impacts of equipment, load, and climate on the energy

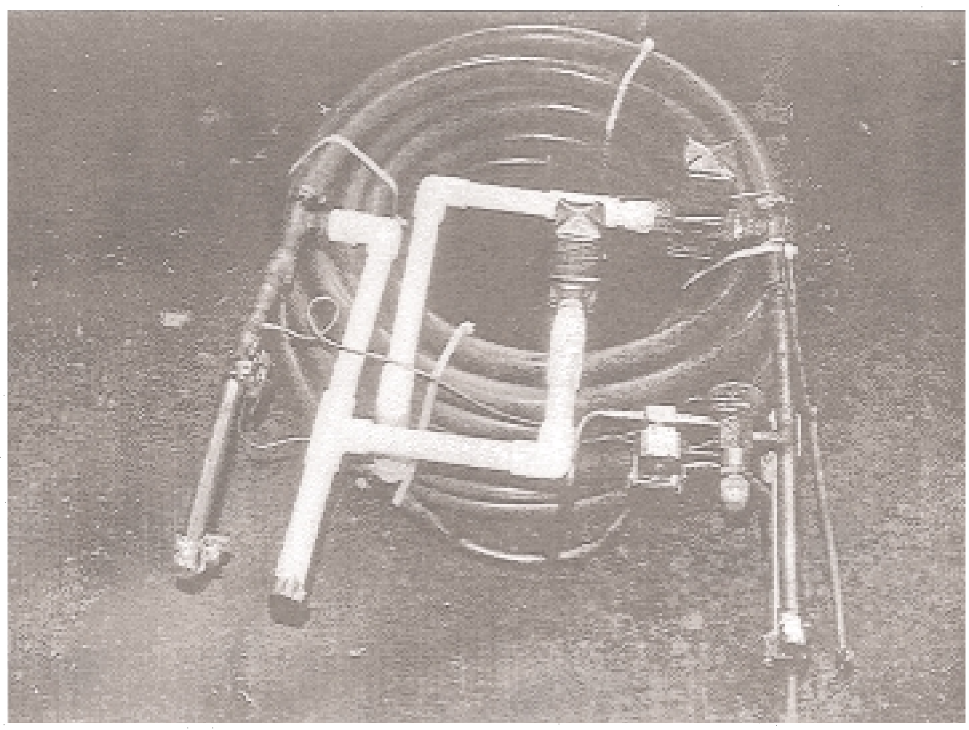


Fig. 1. Subcooling Heat Exchangers

(a) Low-temperature application refers to applications with evaporator temperatures less than -10°F, medium-temperature refers to -10°F to 30°F evaporator temperatures, and high-temperature refers to evaporator temperatures greater than 30°F.

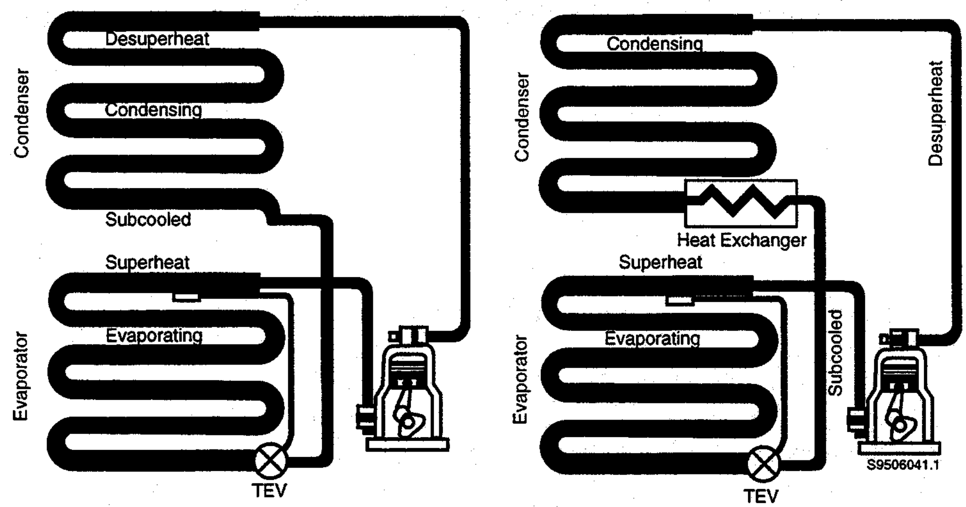


Fig. 2. (a) Conventional Direct Expansion System, (b) System with Subcooler

savings mechanism is essential to proper application of the technology. These topics are reviewed below.

Application Domain

The subcooling technology is generally applicable to direct-expansion vapor-compression equipment with or without head pressure control.

A number of suction-line subcoolers have been installed in low-temperature refrigeration applications. Since these subcoolers are typically sold directly to refrigeration equipment manufacturers, it is difficult to estimate how many are installed in the Federal sector. Although suction-line subcoolers are used primarily in low-temperature refrigeration systems, some manufacturers of packaged and split-system air-conditioners and heat pumps are considering installing these devices in air-conditioning systems using alternative refrigerants (such as HFC-134a).

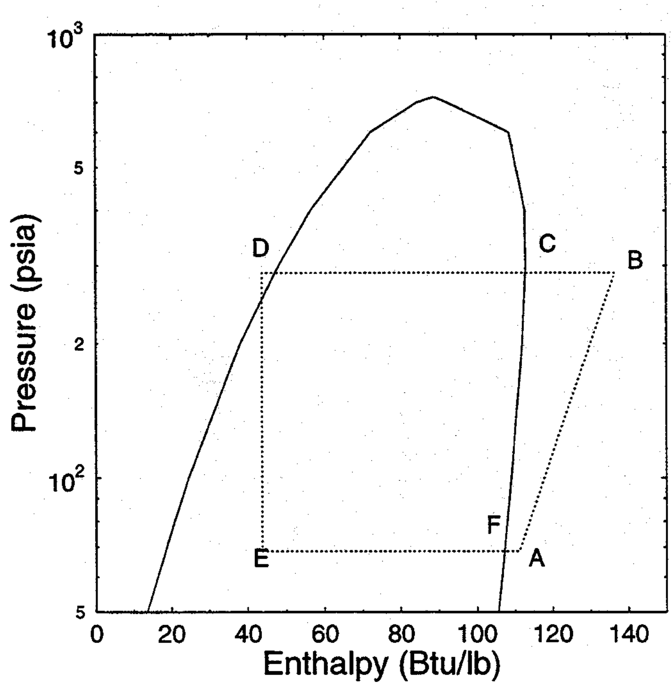


Fig. 3. Pressure-Enthaply Diagram of a Standard Vapor-Compression System

The mechanical subcooling devices are commonly used for both low-and medium-temperature refrigeration. Because the installations are custom designed, no information was readily available pertaining to systems in the Federal sector.

Since 1989, over a dozen systems with external heat sink subcooling devices have been installed, mostly in and around Washington, D.C. Seven of these have been installed at the Internal Revenue Service (IRS) headquarters building. Although an external heat sink subcooling device can be used in both refrigeration and air-conditioning applications, the technology is not recommended for low-temperature refrigeration systems, because it is more expensive and difficult to apply. To date, all installations have been with packaged air-conditioning systems, split-system air-conditioners, and reciprocating chillers. One manufacturer (FTTS) does not recommend the use of an external heat sink subcooling device with centrifugal chillers because its performance is unknown. The manufacturer also recommends that it not be used with existing systems without downsizing the compressor and the condenser. Therefore, an external heat sink subcooling device installation is better suited while replacing existing condensing units (outdoor units). In some cases systems with water-cooled or evaporatively cooled condensers may be cost-effective over a system with an external heat sink subcooling device.

All three subcooling technologies require some custom design and installation for proper operation and to obtain maximum savings potential. For suction-line subcoolers, both the initial investment and benefits are small, but while the initial investment for the external heat sink subcooling device is high, so are the savings. Since the FTTS uses an external sink to reject heat from the refrigerant, a smaller compressor can be used than is feasible with a suction-line subcooler. This increases the overall system performance and efficiency.

Energy-Saving Mechanism

The standard direct-expansion vapor-compression system (Figure 2a) has an evaporator in the fluid stream to be cooled, an expansion valve to meter the flow of refrigerant, a compressor to raise the pressure of the refrigerant vapor, a condenser to reject heat to the outside, and a receiver or accumulator (downstream of the condenser) to store liquid refrigerant. The condenser is usually located outside the building. Conventional refrigeration systems, and some air-conditioning systems (when they operate at low ambient temperatures), incorporate minimum head-pressure controls to ensure that refrigerant pressure between the condenser and the expansion valve is kept high enough to prevent flash gas formation. The minimum head-pressure set-point can often be reduced or eliminated when the system is fitted with a subcooling device. The system topology with a subcooling device (Figure 2b) is identical to that of the standard system, but has a liquid line heat exchanger.

Figure 3 shows the standard vapor-compression cycle on a pressure-enthalpy diagram (ABCDEF) for a normal system. The processes constituting the standard vapor-compression cycle are as follows:

- A-B (compression), superheated vapor is compressed from low (evaporator) pressure to high (condenser) pressure
- B-D (condensation), by rejecting heat at constant pressure (note that there is some pressure drop in the condenser) in the condenser, the superheated refrigerant vapor is condensed to a slightly subcooled state

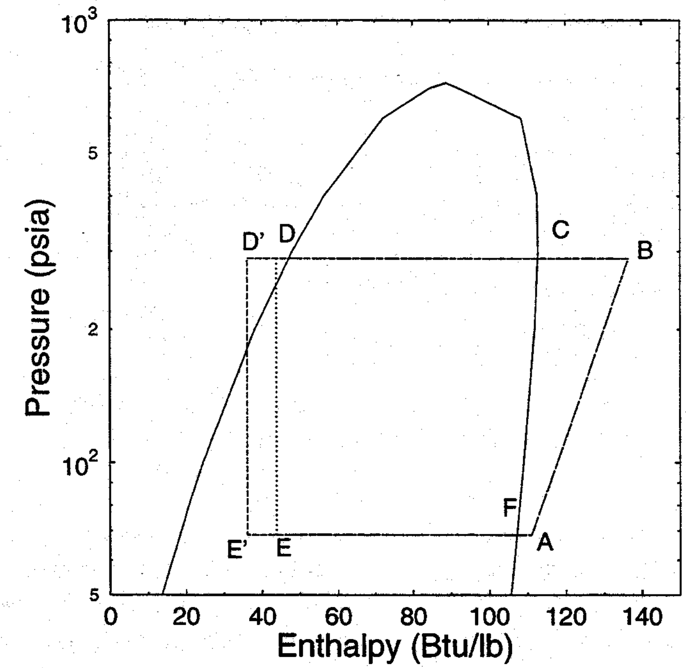


Fig. 4. Pressure-Enthaply Diagram of a Vapor-Compression System with Additional Subcooling

- D-E (expansion), the high-pressure (condenser) liquid refrigerant is reduced to a low-pressure (evaporator) through expansion
- E-A (heat absorption), the refrigerant absorbs heat in the evaporator at constant temperature (note that there is some pressure drop in the evaporator). The amount of heat absorbed by the refrigerant is the cooling capacity of the system.

When the ambient temperature increases, the condenser pressure also increases. Likewise, when the ambient temperature decreases, the condenser pressure decreases. However, at low ambient temperatures (below 60°F [15.6°C]), the minimum head pressure control constrains the cycle. Although the liquid refrigerant leaving the condenser may be subcooled (typically 10°F to 15°F [5.6°C to 8.3°C]), the refrigerant entering the thermostatic expansion valve (TEV)[a] may not be subcooled because of losses in the liquid line. Gas bubbles can form in the liquid refrigerant, resulting in an unstable TEV operation (alternately underfeeding and overfeeding refrigerant to the evaporator).

Figure 4 shows the refrigerant cycle of a system that is identical to that shown in Figure 3, except for additional subcooling (ABCD'E'F). The process constituting the refrigerant cycle with a subcooler is similar to that in Figure 3, except for additional heat rejection at constant pressure and, thus, further subcooling of the refrigerant entering the TEV. Subcooling requires an addition of a heat exchanger downstream of the condenser and a lower temperature sink than the outside air (usually water, ground source or suction-line heat). Subcooling decreases the enthalpy of the refrigerant entering the evaporator, resulting in an increase in the cooling capacity. The amount of subcooling is limited by the temperature of the heat sink.

(a) The abbreviation TXV is used in place of TEV in some literature.

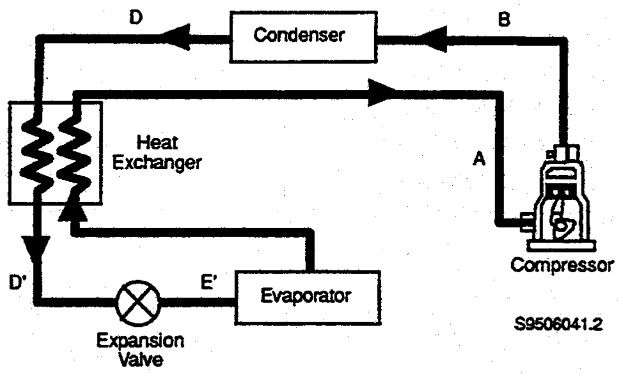


Fig. 5. Conventional Direct-Expansion System with Suction-Line Heat Exchanger

At high ambient air temperatures, the standard direct-expansion, vapor-compression system may achieve about 10°F (5.6°C) subcooling in the condenser, but some of this is lost in the liquid line. Additional subcooling increases the refrigerant cooling capacity by driving the inlet state of the evaporator toward the saturated liquid line and allowing a greater amount of liquid refrigerant in the coil. More liquid refrigerant entering the evaporator wets more of the evaporator surface and increases the heat transfer rate. Also, adjustments to the system are minimized because TEV is handling a greater fraction of the liquid (Couvillion et al. 1988). The rule of thumb is that for every 2°F (1°C) of subcooling, the cooling capacity increases by 1% (Miller 1981; Couvillion et al. 1988). Since subcooling increases the cooling capacity, the compressor and the condensing unit can be downsized, leading to a higher overall efficiency, lower electrical demand and reduced energy consumption.

The amount of energy saved depends on the climatic conditions (outdoor dry-bulb and wet-bulb conditions). At low ambient conditions, the unit is oversized and the available capacity is greater than the load on the evaporator, so subcooling the refrigerant further will not yield any measurable increase in efficiency. However, subcooling the refrigerant at low ambient conditions allows for lowering the minimum head pressure set-point, which may increase the system efficiency. It follows that maximum savings potential exists for high ambient temperature conditions (condensing temperatures above 80°F [26.7°C]). Annual savings are related to the portion of annual compressor run time that occurs under those conditions. Most existing subcooled systems (applied to refrigeration) are installed in areas of relatively hot climates, such as the southeastern region of the United States, where condensing temperatures remain relatively high through most of the year (Couvillion et al. 1988).

Other Benefits

The subcooling technologies offer important benefits besides energy conservation. Since subcooling (with external heat sink) increases the refrigerant capacity, the compressor and the condensing unit can be downsized, with a resulting increase in the overall efficiency and lower electrical demand and energy consumption. Subcooling the refrigerant prevents flash gas from impeding the flow of refrigerant through TEV. The technology offers environmental benefits as well; at least one study has shown that improvement in cooling capacity is even greater with alternative refrigerants (Linton et al. 1992). In facilities where existing cooling capacity is inadequate to meet the cooling load, subcooling technology can provide the additional cooling capacity without a major capital investment.

Variations

As noted above, the three subcooling devices currently being manufactured use either suction-line heat of the vapor-compression system as a heat sink, a secondary vapor compression system for "mechanical" subcooling, or an external heat sink. A number of external heat sink systems are manufactured, most of them as custom-designed units.

- **Suction-line heat exchangers**: Figure 5 shows a typical direct-expansion vapor compression system with a liquid-to-suction heat exchanger. The liquid from the condenser is subcooled by the suction vapor from the evaporator. A suction-line system has more cooling capacity than a standard vapor-compression refrigeration cycle with the same size condenser and compressor, but the power consumption of the compressor also increases because the compression is pushed farther out, into the superheat region, where the compressor must work harder than when it is close to the saturated-vapor line (Stoecker and Jones 1982). Suction-line subcoolers have several advantages: increased cooling capacity, fewer vapor droplets entering the compressor, better expansion valve operation (due to reduced amounts of flash gas), and relatively low cost. As mentioned earlier, however, a suction-line heat exchanger for subcooling can currently be economically applied only to low- or medium-temperature refrigeration systems (Miller 1981). Since none of the manufacturers provided metered data, energy savings potential for a system with suction-line subcoolers was not evaluated.

- **Mechanical Subcooling**: Figure 6 shows a direct-expansion vapor-compression system with a second mechanically driven vapor compression cycle. The two cycles are coupled with a subcooling heat exchanger (subcooler) located downstream of the condenser (Couvillon et al. 1988). Because additional heat is rejected from the main compression cycle, the refrigerant capacity is increased. Mechanical subcooling can subcool the liquid refrigerant more than any other type of subcooling system. The main cycle is similar to that shown in Figure 3. The subcool cycle is similar to that of a conventional cycle, except for saturation temperatures; the saturated evaporating temperature in the subcool cycle is higher than the conventional cycle. Because the temperature extremes are closer in the subcool cycle than in a conventional cycle (the evaporating and condensing temperatures are closer), the subcool cycle is more efficient (Couvillion et al. 1988). Therefore, the combined efficiency of the total system is also higher. Miller (1981) notes that deep mechanical subcooling can result in a 20% to 30% savings in energy use for refrigeration compressors, capital savings through reduction in equipment size, and reduction in maintenance costs by as much as 60%. Because mechanical subcooling is applicable only for low-temperature application and due to lack of meter data, energy savings potential was not evaluated.

- **External Heat Sink Subcooling**: Figure 7 shows a direct-expansion vapor-compression system with an external heat sink subcooling device (such as FTTS). The system consists of a heat exchanger and a mini-cooling tower. The mini-cooling tower can be replaced by a ground-source water loop. Liquid refrigerant from the condenser is circulated in a counter-flow heat exchanger, where it is further subcooled by circulating water. The heat gained by the water is rejected by evaporation in the mini-cooling tower. Additional components required include a pump to circulate water through the heat exchanger and the mini-cooling tower and a fan to circulate outdoor air. Compared with standard vapor-compression refrigeration cycle, the system with an external heat sink subcooling device has increased cooling capacity. Because of the increased available capacity, a smaller compressor and condenser are used. A system incorporating an external heat sink has several of the same advantages as a limited-use suction-line subcooling system: increased cooling capacity, better expansion valve operation (reduced flash gas). In addition, the condensing units and the compressor can be downsized for decreased power consumption and increased overall system efficiency. Because one manufacturer (FTTS) has provided some qualitative data, energy savings potential with an external heat sink subcooling device is evaluated.

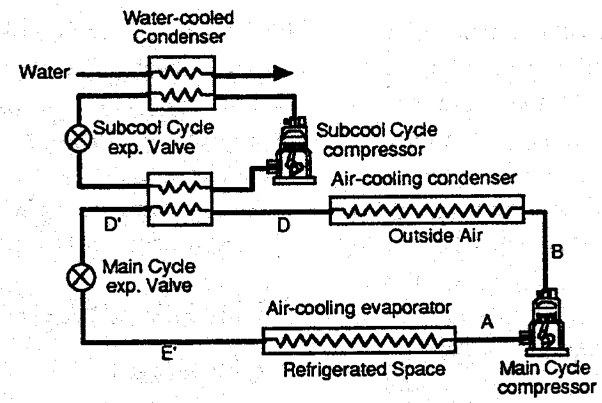


Fig. 6. Conventional Direct-Expansion System with Mechanical Subcooling

Installation

Most installations of external heat sink subcooling devices are custom designed to attain optimum system

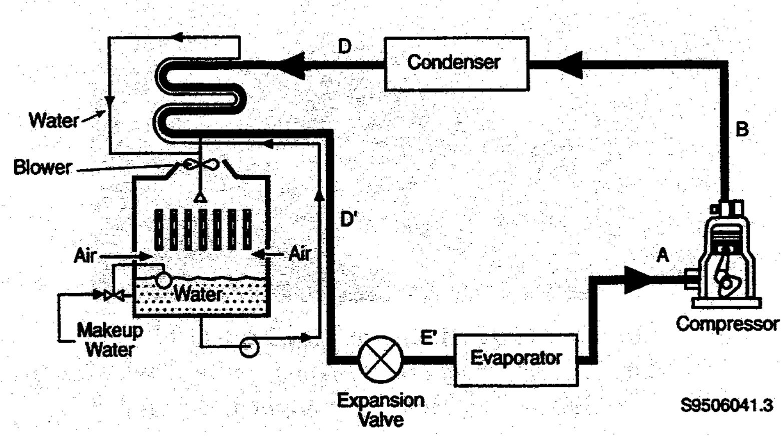


Fig. 7. Conventional Direct-Expansion System with Subcooling Heat Exchangers and Mini-Cooling Tower

performance. To install an external heat sink subcooling device (such as FTTS), one would replace the outdoor fan motors, controls, compressor, condenser, and TEV. If the outdoor unit (condenser and compressor) is not downsized, use of external heat sink subcooling devices is not recommended. The indoor fan, evaporator coil, and cabinet are typically not replaced. The compressor, condenser, and TEVs are downsized, and new controls are installed. Subcooling heat exchanger coils are installed along with a mini-cooling tower (with a water circulation pump and fan). These coils are located in the liquid line (downstream of the condenser), and the controls are adjusted to yield a liquid refrigerant temperature of 80°F (26.7°C). The objective is to reduce the liquid refrigerant temperature to the coldest controllable point while retaining a pressure-temperature relationship at the high-pressure side of the system that does not negate the maximum heat removal capability of the air source heat exchanger/condenser. Some space is required close to the outdoor unit (condenser) to install the heat exchanger coils and the mini-cooling tower. The sizes of the coils and the cooling tower depend on the size of the load being served. Figure 8 shows a photograph of a mini-cooling tower serving two 3-ton (10.5-kW) condensing units.

Federal Sector Potential

The potential cost-effective energy savings achievable by this technology (external heat sink subcooling) were estimated as a part of the technology assessment process of the New Technology Demonstration Program (NTDP). New technologies were identified through advertisements for technology suggestions in the *Commerce Business Daily* and trade journals, and through direct correspondence. Numerous responses were obtained from manufacturers, utilities, trade associations, research institutions, Federal sites, and other interested parties. Based on these responses, the technologies suggested were evaluated in terms of potential Federal-sector energy savings and procurement, installation, and maintenance costs. They were also categorized as either just coming to market ("unproven" technologies) or as technologies for which field data already exist ("proven" technologies).[a]

The energy savings and market potentials of each candidate technology were evaluated using a modified version of the Facility Energy Decision Screening (FEDS) software tool, developed for the Federal Energy Management Program (FEMP), the Civil Engineering Research Laboratory (CERL), and the Naval Facilities Engineering Service Center (NFESC) by Pacific Northwest Laboratory (PNL).

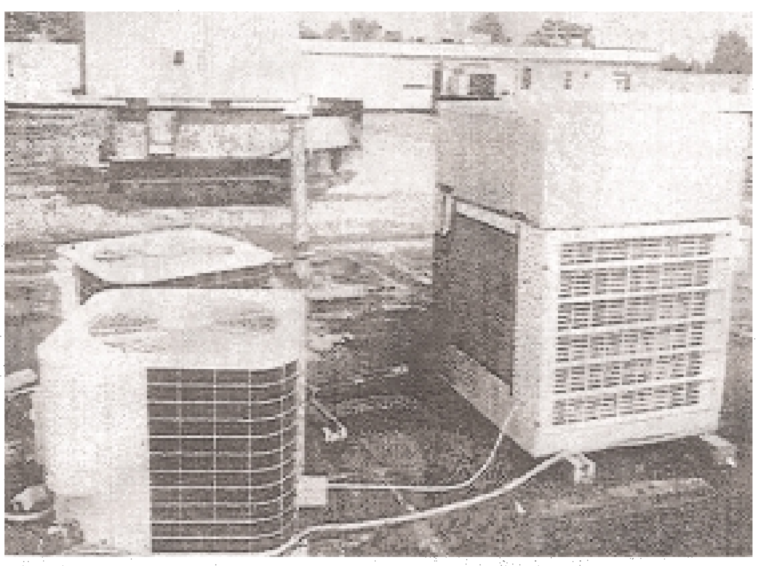


Fig. 8. Shown in the Picture are Two 3-ton (10.5 kW) Condensing Units and a Mini-Cooling Tower (right) with Subcooling Heat Exchanger Coils on Top

Application

This section addresses technical aspects of applying the refrigerant subcooling technology. The range of applications and climates in which the technology can best be applied are discussed. The advantages and limitations of each application are enumerated. Design and integration consideration for only the external heat sink subcooling technology are highlighted, including costs, options, and installation details. Utility incentives are also discussed.

Application Screening

Refrigerant subcooling is a reliable way of increasing cooling capacity and, in some cases, of decreasing compressor power as well. Therefore, the thermodynamic efficiency of a system with a subcooler is higher than that of a system without a subcooler. The annual energy savings is closely tied to the annual load distribution, number of operating hours and the annual ambient temperature distribution. Most common applications of the subcooling technology involve the use of chlorofluorocarbons (CFCs)

(a) Those with significant potential were selected (based on availability of funds) for program participation.

and hydrochlorofluorocarbons (HCFCs), notably CFC-12 (suction-line and mechanical subcooling) and HCFC-22 (external heat sink subcooling). Subcooling devices can also be installed with systems using alternative refrigerants such as HFC-134a.

Where to Apply Subcooling

In general, the benefits from subcooling are higher in regions with high and constant year-round temperatures. The temperature distribution by locations is readily available to most Federal energy managers (TM 5-785, 1978).

- Both suction-line subcooling and mechanical subcooling are applicable in low- and medium-temperature applications such as grocery store and supermarket refrigerators and freezers.
- The external heat sink subcooling can be applied to medium- and high-temperature refrigeration/air-conditioning systems, but it is more economical for high-temperature applications, generally in conjunction with air-conditioning and heat pump systems or reciprocating, screw and scroll chillers.
- Because optimum performance of a system with external heat sink subcooling requires downsizing of the condensing units, the technology is more attractive in installations where the existing units are being replaced (old reciprocating or old packaged or split systems) or where new construction/expansion is planned or where the current equipment capacity is inadequate.

What to Avoid

Again, the varieties of subcooling technology have fairly specific limitations of use.

- Suction-line subcoolers should not be installed on air-cooled direct-expansion air-conditioning, heat pump systems, and large refrigeration systems.
- Subcooling devices are not recommended for centrifugal chillers, because the chillers' performance with an external heat sink subcooling device is unknown.
- External heat sink subcooling systems should be carefully evaluated for off-peak cold storage application because the ambient conditions are generally less severe during off-peak.
- External heat sink subcooling systems should not be used for low-temperature applications.
- Installation of an external heat sink subcooling device may not be possible where the condensers are located indoors or if there is inadequate room for installation of a mini-cooling tower.
- In general, the benefits of subcooling are lower in regions with mild or low year-round temperatures.
- External heat sink subcooling is not recommended as an add-on device.
- In some cases, a system with a water-cooled or evaporatively cooled condenser may be as effective as a system with a subcooler rejecting heat through a mini-cooling tower. However, the cost associated with a water-cooled or evaporatively cooled condenser may be higher.

Equipment Integration

Size and location. Space is required close to the condensing unit (outdoor) to install the heat exchanger coils, but the mini-cooling tower can be remotely located from the condensing unit. Also, the space requirements depend on the size of the condensing unit. Figure 8 shows a typical installation in which two 3-ton (10.5-kW) condensing units are being served by a single mini-cooling tower.

Thermostatic expansion valve. The intended function of the TEV is unchanged by the subcooling device installation. However, the TEV is replaced to match the capacity of the condensing units (which are also generally replaced). New controls are required to maintain a stable pressure-temperature relationship.

Equipment warranties. One manufacturer of the external heat sink subcooling device (FTTS) warranties the subcooling heat exchanger coil for a period of five years and the mini-cooling tower, including the pump and blower, for a period of one year. The prospective user should ensure that the other warranties (condensing units, etc.) are valid when used along with the subcooling system.

Cost

Typical cost of installation of one external heat sink subcooling design (FTTS) is \$700/ton (\$200/kW). Approximately 65% of the installation cost is for the material and the rest for the labor. The cost of installation may vary slightly depending on geographic location (remoteness of the installation), customers specificity of brand name, location and accessibility of existing/proposed equipment, and time allowed for the job to be completed. A typical replacement of an existing system would involve downsizing of outdoor blower and motor, compressor, condenser (outdoor unit), and TEV. The installation cost also includes the subcooling heat exchanger and the mini-cooling tower. The components that are not replaced are the indoor blower and evaporator coil. In case these have to be replaced an additional cost is incurred. The cost also does not include any changes to the air distribution system, and options such as reheat, economizer controls, monitoring points to the energy monitoring and control system, etc.

Utility Incentives and Support

Two utilities, Potomac Electric Power Company (PEPCO) and Baltimore Gas and Electric (BG&E), currently provide incentives for installing FTTS under their commercial DSM program. Virginia Electric Power Company (VEPCO) is considering such an incentive. Other subcooling devices may also qualify for the incentives. Also, facility managers are encouraged to contact their utility representative to check about any custom rebate programs. These programs are not technology-specific but are based on the energy and demand savings regardless of the technology. Other sources of information include a recent publication reporting current demand-side management (DSM) programs by Electric Power Research Institute (EPRI 1993). This report identified 2,321 DSM programs from 666 utilities.

Technology Performance

Over a dozen split systems and packaged systems have been fitted with an external heat sink subcooling device in the last six years. Seven of these are in the Federal sector (IRS headquarters buildings in Washington, D.C.). Observations from the Federal and private-sector users are summarized in this section.

Field Experience

Although over a dozen external heat sink subcooling devices have been installed, performance of the technology has not been monitored at any of the sites. Conversations with the building owners/operators revealed that all have seen a drop in electric consumption after the installation of the subcooling device. The first installation at the only Federal site (IRS building) was in 1989. The operator at the IRS site is satisfied with the performance of the installations and is considering installing another one at that site. Long-term performance of systems with an external heat sink subcooling device is unknown.

Maintenance

For an air-conditioning or refrigeration system with a subcooling device, the required maintenance can be broken down into two parts: 1) the general air-conditioning maintenance, and 2) the maintenance of the subcooling heat exchanger and the mini-cooling tower. A typical yearly maintenance cost for the air-conditioning system is about $25/ton to $35/ton and for the mini-cooling tower it is about 2% of the cost of the cooling tower. When an external heat sink subcooling device, such as the FTTS, is installed with the air-conditioning system, the outdoor unit is downsized; therefore, the general maintenance of the air-conditioning decreases and there is an additional maintenance associated with the external heat sink (mini-cooling tower). In general, reduction in cost of maintaining the air-conditioning system is offset by the additional cost for maintaining the mini-cooling tower. The general maintenance of the air-conditioning system is similar to a conventional system; the mini-cooling towers will need periodic maintenance, such as checking the pre-filter on the makeup water and cleaning the sump. The manufacturer of the FTTS requires that preventive maintenance be done by someone trained by the manufacturer. Candidates for such training are required to have passed the Refrigerant Recovery Course and hold a valid Type III Certification (High Pressure Systems, 50 lbs and over). The manufacturer generally provides training at the time of installation at no additional cost.

Other Impacts

There are no special code compliance issues beyond the usual codes and regulations that must be observed when installing or servicing air-conditioning or refrigeration equipment. All refrigerant-handling regulations must be observed. The energy savings associated with subcooling have a positive impact on the environment. Typical per-MWh emission reductions are 0.3 lbm (0.14 kg) of particulates, 3.3 lbm (1.5 kg) of sulfur oxides, 5.3 lb (2.4 kg) of nitrogen oxides, and 1,720 lb (780 kg) of carbon dioxide. These numbers vary with time and region, depending on the generation mix (EPA 1994; Nemeth 1993).

FTTS Manufacturer's Claims

The FTTS manufacturer states that from his past experience the installed capacity of compressors can be downsized by up to 66% in conjunction with FTTS installation. For example, at one site a 100-ton chiller system was replaced with two 20-ton remote-condensing units with FTTS (for details refer to the Case Study section). Because detailed monitoring and field operational information was not available, it is difficult to verify or replicate through calculations these reductions in demand that occur with FTTS installation.

The review of existing technical literature on refrigerant subcooling and a detailed analysis of thermodynamic cycle indicate that for every 2°F of subcooling the compressor can be downsized by 1%. In a typical installation with 40°F of additional subcooling, the reduction in compressor size would be calculated at 20%.

Theoretically, between 20% and 66% a "gray area" presently exists. While not supported by engineering calculation, the installed systems do operate and effectively condition the buildings served. In considering FTTS it is recommended that the life-cycle cost-effectiveness first be calculated using a figure of 1% reduction in compressor size for every 2°F of additional subcooling provided by the subcooling device. If the installation is life-cycle cost-effective at that point it should be considered for application and the "gray area" above becomes a moot point. If this first LCC calculation does not meet the acceptable payback criteria, then it is recommended the desired result be established and the percent reduction at which the technology is life-cycle cost-effective be estimated. If that percent appears to be within an acceptable limit as stated by the manufacturer (66% reduction), it is recommended other site energy managers employing the subcooling technology (as listed herein) be contacted for additional insight and guidance.

In the case study following this section, we use a 1% reduction in compressor size for every 2°F of additional subcooling provided by the subcooling device. Also, shown in Table 1 is LCC analysis if a compressor were downsized by 66%."

How to Estimate Energy Savings Potential

The following brief example is intended as a basic guideline for estimating potential savings from refrigerant subcooling implementation. The reader should carefully examine all assumptions and modify them to suit specific applications.

In this example it is assumed that an existing nominal 20-ton (70.3-kW) unit is being retired and replaced with another unit with an external heat sink subcooling device. So the comparison is being made between a new 20-ton (70.3-kW) unit and slightly smaller unit with a subcooling device. The rated input power of the nominal 20-ton (70.3-kW) packaged unit (including compressor, outdoor fan, and the indoor blower) is 27.2 kW. The unit with a subcooler has a smaller compressor, condenser, and TEV, and a 20-ton (70.3-kW) evaporator coil.

The compressor, the condenser and the TEV are downsized because for every 2°F (1°C) of subcooling, the cooling capacity increases by 1%. A typical external heat sink subcooling device (FTTS) installation achieves 35°F of additional subcooling with the mini-cooling tower at high outdoor conditions. Further subcooling is possible with ground-source water.

In this example the compressor and the condenser will be downsized by 18%; however, for the unit with a subcooler, there is an additional parasitic power consumption of 1.4 kW by the mini-cooling tower fan and water pump. Therefore, the rated power consumption of the downsized unit would be 22.6 kW (including the parasitic power).

The seasonal savings (or payback of investment) depends on several factors: (1) number of operating hours, (2) climatic conditions, (3) demand and energy charges and (4) utility rebate. In this example the energy savings are estimated by an outdoor temperature bin method. The calculations are performed in a spreadsheet using 5°F (2.8°C) bin data, since this is the form in which the data are readily available to most Federal energy managers (TM 5-785, 1978). The cooling load on the building is assumed to be 230 kBtu/h (67.4 kW) at design condition (96°F [35.6°C] outdoor dry-bulb temperature), and it is also assumed that there is no cooling load on the building below 60°F (15.6°C) outdoor dry-bulb temperature. The building cooling load is linearly interpolated for outdoor temperatures between 96°F (35.6°C) and 60°F (15.6°C). Manufacturers data (for a nominal 20-ton unit) are used to estimate the equipment capacity at various outdoor conditions.

Table 1. Assumption for the Example Case Study

	20-ton Unit	Unit with FTTS	Unit with 66% Downsizing and FTTS[c]
Cooling Capacity	20 tons (70.3 kW)	20 tons (70.3 kW)	20 tons (70.3 kW)
Power Consumption	27.2 kW	22.6 kW	22.6 kW
Demand Charge	$10 kW-month[a]	$10 kW-month	$10 kW-month
Energy Charge	$0.05/kWh	$0.05/kWh	$0.05/kWh
Cost of Unit	$9,000	$14,000[b]	$14,000
Utility Rebate	$0	$0	$0
Annual Energy Consumption	49,997 kWh	44,471 kWh	16,608 kWh
Equipment Life	15 years	15 years	15 years
LCC	$59,116	$57,396	$30,648

(a) Demand Charges are assumed to apply for six months in a year.
(b) Cost of unit with an external heat sink subcooling device, FTTS, is at $700/ton.
(c) Analysis based on a 66% downsizing of the compressor for comparison.

(a) BLCC 4.0 is available from National Institute for Standards and Technology (NIST).

Fig. 9. Shown in the Picture is One of the Two 15-ton (52.7 kW) Condensing Units and the Two Mini-Cooling Towers at the Southwestern University Site

The details of the bin analysis for the two alternatives are shown in Appendix A. The cost of the nominal 20-ton (70.3-kW) unit is estimated to be $9,000 (including installation) and the cost of the unit with the subcooler (FTTS) is estimated to be $14,000 (includes cost for compressor, condenser, subcooling heat exchanger, and a mini-cooling tower to provide 20-tons of cooling and labor charges for installation). Because the compressor and condenser are downsized, the general maintenance of the air-conditioning system decreases; however, there is an additional maintenance associated with the external heat sink (mini-cooling tower). In general, reduction in cost of maintaining the air-conditioning system is offset by the additional cost for maintaining the mini-cooling tower. Therefore, operation and maintenance costs are assumed to be the same for both units. The energy and demand charges are shown in Table 1. Feeding these numbers, and the annual energy use numbers (from the spreadsheet), to the Building Life-Cycle Cost Software (BLCC 4.0)[a] yields a life-cycle cost (LCC) of $59,116 for the 20-ton unit and $57,396 for the unit with FTTS (comparative economic analysis table is provided in Appendix A).

In this example it is assumed that the unit with a subcooler is downsized; however, if one has to install the external heat sink subcooling device on an existing unit without downsizing, the economics may not be favorable (the manufacturer of FTTS does not recommend this option). For example, let us consider a case where the subcooler is added to the existing 20-ton unit. The implementation cost for the subcooler is about $4,500 (cost for just the heat exchanger and the mini-cooling tower) and there is no investment associated with the existing unit. In this case, there is no demand reduction; however, there is a reduction in the energy consumption (45,276 kWh) because of increased cooling capacity. The LCC cost for the unit with a subcooler is $56,276 compared with the LCC of the existing unit of $50,116. Therefore, if the unit cannot be downsized, then the subcooler implementation is not economical.

Case Study

Although more than a dozen external heat sink subcooling devices have been installed, performance of the technology has not been monitored at any of the sites. Therefore, a qualitative analysis was performed on the basis of whole-building utility billing information. Although seven subcooling systems have been installed at the Internal Revenue Service headquarters in Washington, D.C., they were not considered as good candidates for a case study because the energy use of the systems is a small fraction of the whole-building utility bill. Instead, a private-sector site with historical utility billing information was selected for further study, Southeastern University. This facility, its systems, and the estimated savings potentials are described below.

Southeastern University

The case study focuses on an installation at Southeastern University (SU), Washington, D.C. The building has about 46,000 ft^2 (4274 m^2) of conditioned area and is conditioned from 8 a.m. to 10 p.m. every day. The annual heating Fahrenheit degree-days for this location are 4,729 (2,627°C-days) and the cooling degree-days are 1,107 (615°C-days). The 2.5% cooling design temperature for this location is 89°F (31.7°C).

The utility that serves SU is PEPCO. The off-peak electricity price (for June through October) is $0.02874/kWh (midnight to 8 a.m. all days, and 12 noon to 8 p.m. on holidays); intermediate-peak electricity price is $0.04144/kWh (8 a.m. to 12 noon, and 8 p.m. to midnight, all days); and on-peak electricity price is $0.05688/kWh (12 noon to 8 p.m., Monday through Friday, excluding holidays). In addition to the energy charge (kWh), the utility also has a general demand charge of $6.65/kW-month and a summer (June through October) on-peak demand charge of $10.65/kW-month; there is no ratchet clause.

Pre- and post-replacement systems. The pre-replacement air-conditioning system was a 22-year-old 100-ton (352-kW) chiller system with a cooling tower. The total rated input for the chiller, the chilled water pump, the condenser pump, and the cooling tower fan is about 123 kW (equivalent energy efficiency ratio of 9.8). The chiller system was replaced with two nominal 20-ton (70-kW) remote condensing units, each fitted with an external heat sink subcooling device, a 100-ton (352-kW) chiller barrel with dual-circuited refrigerant systems (each circuit being used independently for one unit), and two mini-cooling towers (Figure 9). The mini-cooling towers discharge air directly into the air-cooled condensers. Each mini-cooling tower has a fan and a water-circulating pump. The total power consumption for the fan and pump is 1.4 kW. The controls on the replaced system are adjusted to provide an 80°F (26.7°C) liquid refrigerant temperature (approximately 35°F [19.4°C] of subcooling). By comparison, a standard system would provide 110°F (43°C) to 115°F (46°C) liquid refrigerant temperature. The Air Conditioning and Refrigeration Institute-rated Energy Efficiency Ratio (EER) of the new condensing units is 10, and the equivalent EER of the new system with the subcooler is about 9.7. The total capital investment for this installation was $128,000 (cost of the installation also included a new 100-ton chiller barrel which had to be replaced because it was broken; therefore, the installation cost exceeded the $700/ton estimate). The cost of the mini-cooling towers and subcooling coils is $4,900/each (which is included in the total capital investment of $128,000). A portion of the installation cost ($60,500) was recovered from PEPCO as a part of their custom rebate program.

Table 2. Pre- and Post-Replacement Demand and Energy Consumption at the Southeastern University Site

Month	Maximum Dry-Bulb Temperature (°F) Pre	Maximum Dry-Bulb Temperature (°F) Post	Demand (kW) Pre	Demand (kW) Post	Cooling Degree-Days[a] Pre	Cooling Degree-Days[a] Post	Energy (kWh) Pre	Energy (kWh) Post
May	89	92	126	86	63	53	32,850	28,350
June	96	101	131	99	144	234	44,550	32,850
July	100	98	144	99	516	542	55,800	45,450
August	96	93	122	104	470	436	53,100	49,050
September	96	91	153	95	447	252	57,150	43,200
October	80	81	117	99	52	95	36,000	36,900

(a) Cooling degree days are to base 65°F (18.3°C).

Savings potential. Since neither the performance of the pre-replacement unit nor that of the new system has been monitored, utility bills from pre- and post-replacement periods were used to compare the performance. A qualitative assessment of the technology is possible at this site because the load from the air-conditioning equipment is at least 30% of the total load. Table 2 shows the pre- and post-replacement demand, energy consumption, and reduction in demand and energy consumption after replacement. The reduction in demand and the energy consumption are normalized for changes in climatic conditions from pre- to post-replacement period (using the cooling degree-days).

Table 3 shows the reduction in demand and energy consumption (after normalization). An on-peak demand charge of $10.65/kW-month and distribution demand charge of $6.65/kW-month were used to estimate the reduction in demand cost. Since the air-conditioning system operates between 8 a.m. and 10 p.m, seven days a week, an average of the on-peak and intermediate-peak kWh-charge was used to estimate the energy reduction ($0.04916/kWh).

With just the whole-building utility billing data, it is difficult to quantify the actual reduction of demand and energy consumption that can be attributed to the subcooling device alone. Because there was no other change to the building during the one-year period (peak demand and energy consumption remained unchanged during winter months), significant portion of the energy and demand reduction can be attributed to the retrofit.

Table 3. Demand and Energy Reduction at the Southeastern University Site after Normalizing the Pre-Replacement Values to Post Conditions

	Demand					Energy Consumption				
Month	Max Dry-Bulb (°F)	Pre	Post	Diff. (kW)	Diff. ($)	Cooling Degree Days	Pre	Post	Diff. (kWh)	Diff. ($)
May	92	127	86	41	703	53	32,136	28,350	3,786	186
June	101	133	99	34	588	234	51,863	32,850	19,013	935
July	98	143	99	44	761	542	56,322	45,450	10,872	535
August	93	121	104	17	294	436	52,807	49,050	3,757	185
September	91	149	95	54	934	252	51,064	43,200	7,864	387
October	81	117	99	18	311	95	36,000	36,900	NA	NA

The total annual savings in demand and energy charges at SU are $5,819. The net cost of the retrofit is $67,500, which yields a simple return of investment of about 11.6 years.

Implementation and post-implementation experience. The installation was completed in March 1993. Since the existing chiller had to be replaced, several days were necessary to complete the retrofit. The building occupants are satisfied with the operation of the new system.

Savings potential

Comparison of the electric utility bills from pre- and post-replacement at one site indicates demand and energy savings. The savings are from installing the subcooling device, which enabled downsizing of the existing system.

The Technology in Perspective

The refrigerant subcooling technology has a good potential in the Federal sector because it not only provides for additional cooling capacity but can also reduce compressor power, leading to a higher overall system efficiency. Potential applications include direct-expansion vapor-compression air-conditioning equipment. The technology is especially useful where the reciprocating chillers, split systems or packaged systems are to be replaced (equipment that has operated for 15 years or longer) or on new installations. It is not economical to install an external heat sink subcooling device with an existing unit, if the compressor and the condenser cannot be downsized.

Manufacturers

FTTS Automatic Controls, Inc.
P.O. Box 570
Ellicott City, MD 21041-570
Ralph Fisher, CEO (410)461-7995; Fax (410)461-7957

Suction-Line Heat Exchangers (subcoolers)

Alfa Laval Thermal Inc.
5400 International Trade Drive
Richmond, VA 23231
(804)236-1362; Fax (804)236-1303

Doucette Industries
P.O. Box 2337
York, PA 17405
(717)845-8746; Fax (717)845-2864

Packless Industries
P.O. Box 20668
Waco, TX 76702
(817)666-7700; Fax (817)666-7893

Refrigeration Research
P.O. Box 869
Brighton, MI 48116-0869
(810)227-1151; Fax (810)227-3700

Turbotec Products Inc.
651 Day Hill Road
Windsor, CT 06095
(203)683-2005; Fax (203)683-2133

Who Is Using the Technology

Contacts for the IRS headquarters buildings and the case study site are provided below. The reader is invited to ask questions and learn more about the new technology.

Internal Revenue Service
1111 Constitution Avenue, N.W.
Washington, D.C., 20224
Contact: Mr. Kelvin Mims
General Foreman, O&M Shop
(202)622-6044.

Southeastern University
501 Eye Street, S.W.
Washington, D.C., 20224
Contact: Mr. Jack H. DeBruin
Chief Financial Officer
(202)488-8162.

For Further Reading

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Appendixes

Appendix A: Results for the Example Case Study

Appendix B: Federal Life-Cycle Costing Procedures and the BLCC Software

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Appendix A

Results for the Example Case Study

Energy Consumption with the 20-Ton Unit Without Subcooling by Bin Method[a]

Location	Tinker AFB, OK
Number of Units	1
Facility design load	230 kBtu/h
Facility design temperature	96°F
Facility balance temperature	60°F
A/C nominal capacity	20 tons
Rated evaporator air flow	7000 cfm/unit
Bypass factor	0.075
Fan indoor entering air conditions	80°Fdb
Fan indoor entering air conditions	67°Fwb
Part load degradation factor	0.25
Indoor air fan load	3.60 kW
Outdoor air fan load	3.00 kW

Avg. Bin Temp. (°F) (1)	Bin Hours (h/yr) (2)	Bldg. Load (kBtu/h) (3)	Net Equip. Capacity (4)	Theor. Run Time (%) (5)	Partial Load Factor (6)	Actual Run Time (7)	A/C Eff'y. (EER) (8)	A/C Input Power (kW) (9)	A/C Energy (kWh) (10)	Fan Energy (kWh) (11)	Total Electric Energy (kWh) (12a)
Cooling Mode:											
112	0	332	211.62	1.00	1.00	1.00	9.04	23.41	0	0	0
107	1	300	218.32	1.00	1.00	1.00	9.66	22.59	23	7	29
102	18	268	224.00	1.00	1.00	1.00	10.29	21.78	392	119	511
97	94	236	229.00	1.00	1.00	1.00	10.93	20.96	1,970	620	2,591
92	240	204	234.00	0.87	0.97	0.90	11.62	20.14	4,362	1,429	5,791
87	393	173	239.00	0.72	0.93	0.78	12.37	19.33	5,892	2,012	7,904
82	603	141	244.00	0.58	0.89	0.64	13.18	18.51	7,192	2,564	9,756
77	829	109	249.00	0.44	0.86	0.51	14.07	17.69	7,448	2,778	10,226
72	948	77	254.00	0.30	0.83	0.37	15.05	16.88	5,850	2,288	8,138
67	819	45	259.00	0.17	0.79	0.22	16.13	16.06	2,863	1,177	4,040
62	729	13	264.00	0.05	0.76	0.06	17.32	15.24	706	306	1,011
Total									36,697	13,300	49,997

(a) The description of each column is provided on the next page.

Energy Savings Analysis with an External Heat Sink Subcooling Device by Bin Method

Location .... Tinker AFB, OK
Number of Units 1
Facility design load .... 230 kBtu/h
Facility design temperature .... 96°F
Facility balance temperature .... 60°F
A/C nominal capacity .... 16 tons
Rated evaporator air flow .... 7000 cfm/unit
Bypass factor 0.075
Fan indoor entering air conditions .... 80°Fdb
Fan indoor entering air conditions .... 67°Fwb
Part load degradation factor 0.25
Indoor air fan load .... 3.60 kW
Outdoor air fan load .... 2.50 kW
Cooling tower fan input power .... 1.40 kW

Avg. Bin Temp. (°F) (1)	Bin Hours (h/yr) (2)	Bldg. Load (kBtu/h) (3)	Net Equip. Capacity (4)	Theor. Run Time (%) (5)	Partial Load Factor (6)	Actual Run Time (7)	A/C Eff'y. (EER) (8)	A/C Input Power (kW) (9)	A/C Energy (kWh) (10)	Fan Energy (kWh) (11)	Cooling Tower Energy (kWh) (12b)	Total Electric Energy (kWh) (13)
Cooling Mode:												
112	0	332	211.62	1.00	1.00	1.00	11.30	18.73	0	0	0	0
107	1	300	218.32	1.00	1.00	1.00	12.08	18.07	18	6	1	25.575
102	18	268	224.00	1.00	1.00	1.00	12.86	17.42	314	110	25	448.58
97	94	236	229.00	1.00	1.00	1.00	13.66	16.77	1,576	573	132	2281.2
92	240	204	234.00	0.87	0.97	0.90	14.52	16.11	3,489	1,321	303	5113.1
87	393	173	239.00	0.72	0.93	0.78	15.46	15.46	4,713	1,860	427	6999.9
82	603	141	244.00	0.58	0.89	0.64	16.48	14.81	5,753	2,370	544	8667.5
77	829	109	249.00	0.44	0.86	0.51	17.59	14.15	5,958	2,568	589	9115.2
72	948	77	254.00	0.30	0.83	0.37	18.81	13.50	4,680	2,115	485	7280
67	819	45	259.00	0.17	0.79	0.22	20.16	12.85	2,291	1,088	250	3628
62	729	13	264.00	0.05	0.76	0.06	21.65	12.19	565	282	65	911.83
Total									29,358	12,292	2,821	44,471

Notes:

Column	Description or equation
(1)	Midpoint of temperature bin from weather data
(2)	Number of hours in temperature bin from weather data
(3)	= (average bin temp. - fac. balance temp.) * [fac. design load / (fac. design temp. - fac. balance temp]
(4)	based on equipment specifications corrected for actual conditions
(5)	= column (3) / column (4); maximum = 1.0
(6)	= 1.0 - degradation factor * {1.0 - [column (3) / column (4)]}; maximum = 1.0
(7)	= [column (5) / column (6)]
(8)	= [column (4) / column (9)]
(9)	Based on equipment specifications corrected for actual conditions
(10)	= column (2) * column (7) * column (9)
(11)	= column (2) * column (7) * (indoor air fan load + outdoor air fan load)
(12a)	= column (10) + column (11)
(12b)	Cooling tower fan energy
(13)	= column (10) + column (11) + column (12)

Note: Note 12a applies to the unit without subcooling, and 12b and 13 only apply to the unit with subcooling. The rest of the notes are common to both tables.

BLCC 4.0: COMPARATIVE ECONOMIC ANALYSIS

BASE CASE: Conventional
ALTERNATIVE: FTTS

PRINCIPAL STUDY PARAMETERS:

ANALYSIS TYPE: Federal Analysis--Energy Conservation Projects
STUDY PERIOD: 15.00 YEARS (JAN 1995 THROUGH DEC 2009)
DISCOUNT RATE: 3.0% Real (exclusive of general inflation)
BASE CASE LCC FILE: BASEN001.LCC
ALTERNATIVE LCC FILE: FTTSN001.LCC

COMPARISON OF PRESENT-VALUE COSTS

	BASE CASE: Conventional	ALTERNATIVE: FTTS	SAVINGS FROM ALT.
INITIAL INVESTMENT ITEM(S):			
CASH REQUIREMENTS AS OF SERVICE DATE	$9,000	$14,000	-$5,000
SUBTOTAL	$9,000	$14,000	-$5,000
FUTURE COST ITEMS:			
ENERGY EXPENDITURES	$50,116	$43,396	$6,720
SUBTOTAL	$50,116	$43,396	$6,720
TOTAL P.V. LIFE-CYCLE COST	$59,116	$57,396	$1,720

NET SAVINGS FROM ALTERNATIVE FTTS COMPARED TO ALTERNATIVE Conventional

Net Savings	= P.V. of non-investment savings	$6,720
	- Increased total investment	$5,000
	Net Savings:	$1,720

Note: the SIR and AIRR computations include differential initial costs, capital replacement costs, and resale value (if any) as investment costs, per NIST Handbook 135 (Federal and MILCON analyses only).

SAVINGS-TO-INVESTMENT RATIO (SIR)
FOR ALTERNATIVE FTTS COMPARED TO ALTERNATIVE Conventional

$$\text{SIR} = \frac{\text{P.V. of non-investment savings}}{\text{Increased total investment}} = 1.34$$

ADJUSTED INTERNAL RATE OF RETURN (AIRR)
FOR ALTERNATIVE FTTS COMPARED TO ALTERNATIVE Conventional
(Reinvestment rate = 3.00%; Study period = 15 years)

AIRR = 5.05%

ESTIMATED YEARS TO PAYBACK

Simple Payback occurs in year 9
Discounted Payback occurs in year 11

ENERGY SAVINGS SUMMARY

Energy type	Units	---Annual Consumption--- Base Case	Alternative	Energy Savings
Electricity	kWh	49,997	44,471	5,526

Appendix B

Federal Life-Cycle Costing Procedures and the BLCC Software

Federal agencies are required to evaluate energy-related investments on the basis of minimum life-cycle costs (10 CFR Part 436). A life-cycle cost evaluation computes the total long-run costs of a number of potential actions, and selects the action that minimizes the long-run costs. When considering retrofits, sticking with the existing equipment is one potential action, often called the *baseline* condition. The life-cycle cost (LCC) of a potential investment is the present value of all of the costs associated with the investment over time.

The first step in calculating the LCC is the identification of the costs. *Installed Cost* includes cost of materials purchased and the labor required to install them (for example, the price of an energy-efficient lighting fixture, plus cost of labor to install it). *Energy Cost* includes annual expenditures on energy to operate equipment. (For example, a lighting fixture that draws 100 watts and operates 2,000 hours annually requires 200,000 watt-hours (200 kWh) annually. At an electricity price of $0.10 per kWh, this fixture has an annual energy cost of $20.) *Nonfuel Operations and Maintenance* includes annual expenditures on parts and activities required to operate equipment (for example, replacing burned out light bulbs). *Replacement Costs* include expenditures to replace equipment upon failure (for example, replacing an oil furnace when it is no longer usable).

Because LCC includes the cost of money, periodic and aperiodic maintenance (O&M) and equipment replacement costs, energy escalation rates, and salvage value, it is usually expressed as a present value, which is evaluated by

$$LCC = PV(IC) + PV(EC) + PV(OM) + PV(REP)$$

where PV(x) denotes "present value of cost stream x,"
IC is the installed cost,
EC is the annual energy cost,
OM is the annual nonenergy O&M cost, and
REP is the future replacement cost.

Net present value (NPV) is the difference between the LCCs of two investment alternatives, e.g., the LCC of an energy-saving or energy-cost-reducing alternative and the LCC of the existing, or baseline, equipment. If the alternative's LCC is less than the baseline's LCC, the alternative is said to have a positive NPV, i.e., it is cost-effective. NPV is thus given by

$$NPV = PV(EC_0) - PV(EC_1)) + PV(OM_0) - PV(OM_1)) + PV(REP0) - PV(REP_1)) - PV(IC)$$

or

$$NPV = PV(ECS) + PV(OMS) + PV(REPS) - PV(IC)$$

where subscript 0 denotes the existing or baseline condition,
subscript 1 denotes the energy cost saving measure,
IC is the installation cost of the alternative (note that the IC of the baseline is assumed zero),
ECS is the annual energy cost savings,
OMS is the annual nonenergy O&M savings, and
REPS is the future replacement savings.

Levelized energy cost (LEC) is the breakeven energy price (blended) at which a conservation, efficiency, renewable, or fuel-switching measure becomes cost-effective (NPV >= 0). Thus, a project's LEC is given by

$$PV(LEC*EUS) = PV(OMS) + PV(REPS) - PV(IC)$$

where EUS is the annual energy use savings (energy units/yr). Savings-to-investment ratio (SIR) is the total (PV) savings of a measure divided by its installation cost:

$$SIR = (PV(ECS) + PV(OMS) + PV(REPS))/PV(IC).$$

Some of the tedious effort of life-cycle cost calculations can be avoided by using the Building Life-Cycle Cost software, BLCC, developed by NIST. For copies of BLCC, call the FEMP Help Desk at (800) 566-2877.

About the Federal Technology Alerts

The Energy Policy Act of 1992, and subsequent Executive Orders, mandate that energy consumption in the Federal sector be reduced by 30% from 1985 levels by the year 2005. To achieve this goal, the U.S. Department of Energy s Federal Energy Management Program (FEMP) is sponsoring a series of programs to reduce energy consumption at Federal installations nationwide. One of these programs, the New Technology Demonstration Program (NTDP), is tasked to accelerate the introduction of new energy-saving technologies into the Federal sector and to improve the rate of technology transfer.

As part of this effort, FEMP, in a joint venture with the Department of Defense s Strategic Environmental Research and Development Program (SERDP), is sponsoring a series of Federal Technology Alerts (FTAs) that provide summary information on candidate energy-saving technologies developed and manufactured in the United States. The technologies featured in the Technology Alerts have already entered the market and have some experience but are not in general use in the Federal sector. Based on their potential for energy, cost, and environmental benefits to the Federal sector, the technologies are considered to be leading candidates for immediate Federal application.

The goal of the Technology Alerts is to improve the rate of technology transfer of new energy-saving technologies within the Federal sector and to provide the right people in the field with accurate, up-to-date information on the new technologies so that they can make educated judgments on whether the technologies are suitable for their Federal sites.

Because the Technology Alerts are cost-effective and timely to produce (compared with awaiting the results of field demonstrations), they meet the short-term need of disseminating information to a target audience in a timeframe that allows the rapid deployment of the technologies and ultimately the saving of energy in the Federal sector.

The information in the Technology Alerts typically includes a description of the candidate technology; the results of its screening tests; a description of its performance, applications and field experience to date; a list of potential suppliers; and important contact information. Attached appendixes provide supplemental information and example worksheets on the technology.

FEMP sponsors publication of the Federal Technology Alerts to facilitate information-sharing between manufacturers and government staff. While the technology featured promises significant Federal-sector savings, the Technology Alerts do not constitute FEMP s endorsement of a particular product, as FEMP has not independently verified performance data provided by manufacturers. FEMP encourages interested Federal energy and facility managers to contact the manufacturers and other Federal sites directly, and to use the worksheets in the Technology Alerts to aid in their purchasing decisions.

Federal Energy Management Program

The Federal Government is the largest energy consumer in the nation. Annually, in its 500,000 buildings and 8,000 locations worldwide, it uses nearly two quadrillion Btu (quads) of energy, costing over $11 billion. This represents 2.5% of all primary energy consumption in the United States. The Federal Energy Management Program was established in 1974 to provide direction, guidance, and assistance to Federal agencies in planning and implementing energy management programs that will improve the energy efficiency and fuel flexibility of the Federal infrastructure.

Over the years several Federal laws and Executive Orders have shaped FEMP's mission. These include the Energy Policy and Conservation Act of 1975; the National Energy Conservation and Policy Act of 1978; the Federal Energy Management Improvement Act of 1988; and, most recently, Executive Order 12759 in 1991, the National Energy Policy Act of 1992 (EPACT), and Executive Order 12902 in 1994.

FEMP is currently involved in a wide range of energy-assessment activities, including conducting New Technology Demonstrations, to hasten the penetration of energy-efficient technologies into the Federal marketplace.

Strategic Environmental R&D Program

The Strategic Environmental Research and Development Program, SERDP, co-sponsor of these Federal Technology Alerts, was created by the National Defense Authorization Act of 1990 (Public Law 101-510). SERDP's primary purpose is to "address environmental matters of concern to the Department of Defense and the Department of Energy through support for basic and applied research and development of technologies that can enhance the capabilities of the departments to meet their environmental obligations." In 1993, SERDP made available additional funds to augment those of FEMP, for the purpose of new technology installations and evaluations.

For More Information

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